

Airborne Lidar Measurements of Water Vapor, Aerosols, and Clouds During the NASA CAMEX-4 Experiment

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CAMEX Workshop - March 13, 2002

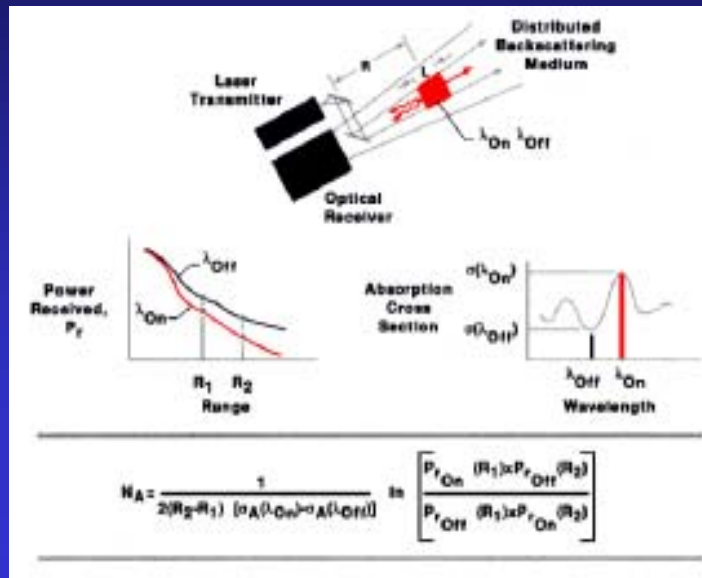


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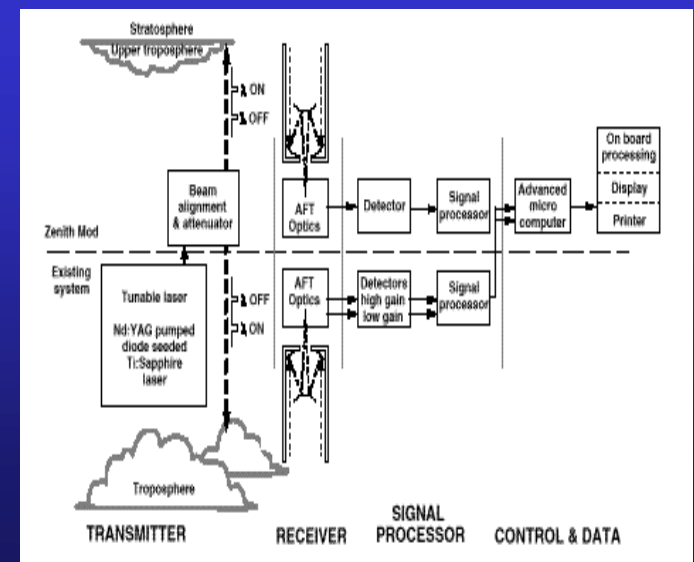
Outline

- **LASE system and measurements**
- **CAMEX-3 and CAMEX-4 Objectives**
- **CAMEX-3**
 - **examples**
 - **LASE/dropsonde water vapor comparisons**
 - **model results using LASE water vapor profiles**
- **CAMEX-4**
 - **status**
 - **examples**
 - **future activities**
- **Summary**

Lidar Atmospheric Sensing Experiment (LASE)



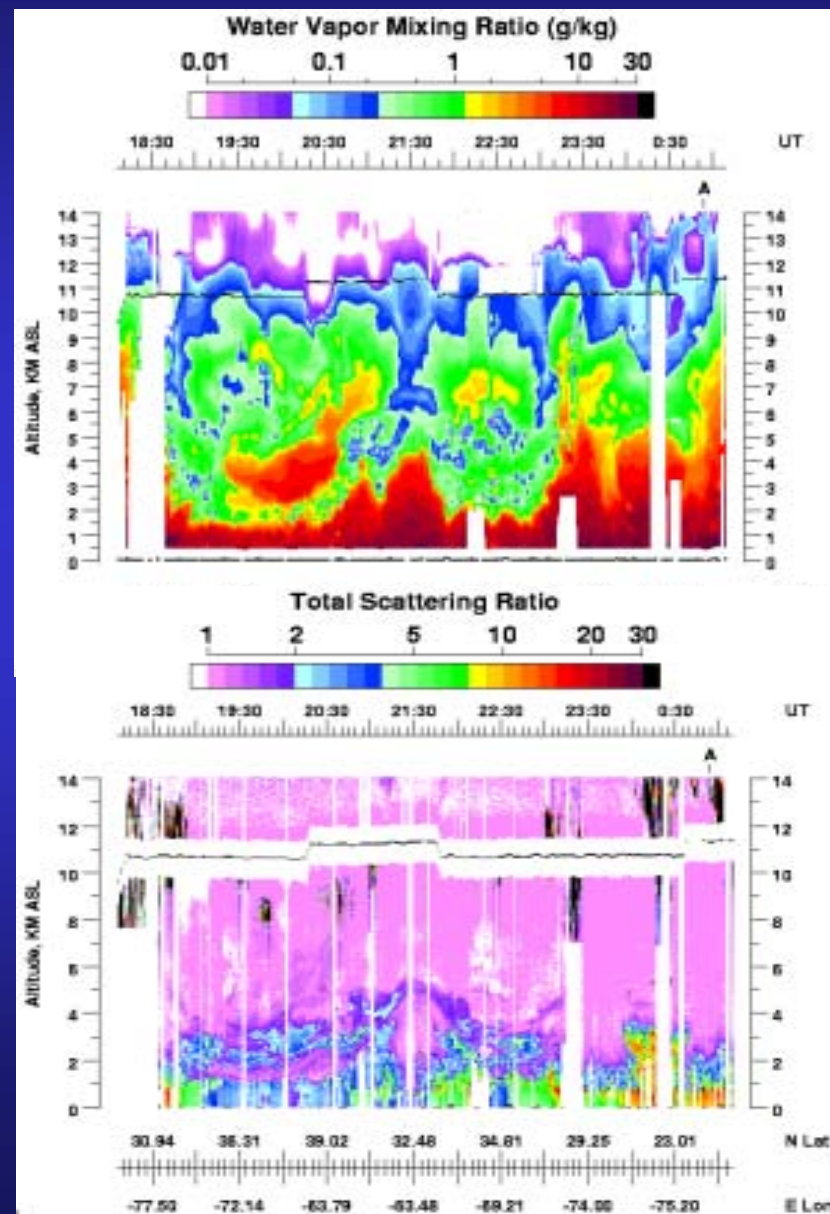
- Airborne Water Vapor DIAL
- Laser
 - 5 Hz doubled-pulsed Ti:sapphire
 - 100 mj (on and off lines)
- Wavelengths
 - 815 nm (on-off $\lambda = \Delta\lambda = 40\text{-}70$ pm)
 - Three separate line pairs
- NASA ER-2, P-3, DC-8 aircraft
- Simultaneous nadir, zenith operations
- Real-time data analysis and display



LASE Water Vapor and Aerosol/Cloud Profiling on NASA DC-8

- Water vapor profiles
 - daytime and nighttime
 - 0.2 km to tropopause (12-14 km)
 - 0.01 to 25 g/kg
 - accuracy (6% or 0.01 g/kg)
 - resolution (variable)
 - 330 m (vertical)
 - 42 km (3 min) (horizontal)
 - DC-8 in situ used within +/- 1 km of plane
- Aerosol/cloud profiles
 - daytime and nighttime
 - 0.03 to 25 km
 - resolution (variable)
 - 30 m (vertical)
 - 200 m (horizontal)

CAMEX3 DC-8 Flight 7 T.S. Bonnie Synoptic Flow Aug. 21-22, 1998



LASE Investigations during CAMEX-3 and CAMEX-4

Objectives:

- provide real-time water vapor, cloud profiles to assist in flight planning and execution
- help assess utility of high resolution water vapor profiles in forecasting storm track and intensity
- evaluate DC-8 and ER-2 dropsonde performance

Research Activities:

- produce Relative Humidity (RH) profiles using LASE water vapor and dropsonde/MTP temperature profiles (focus on upper troposphere RH)
- compute total precipitable water vapor using LASE water vapor profiles
- retrieve cirrus cloud optical and geometrical thickness from LASE cloud profiles
- compare/evaluate other water vapor measurements

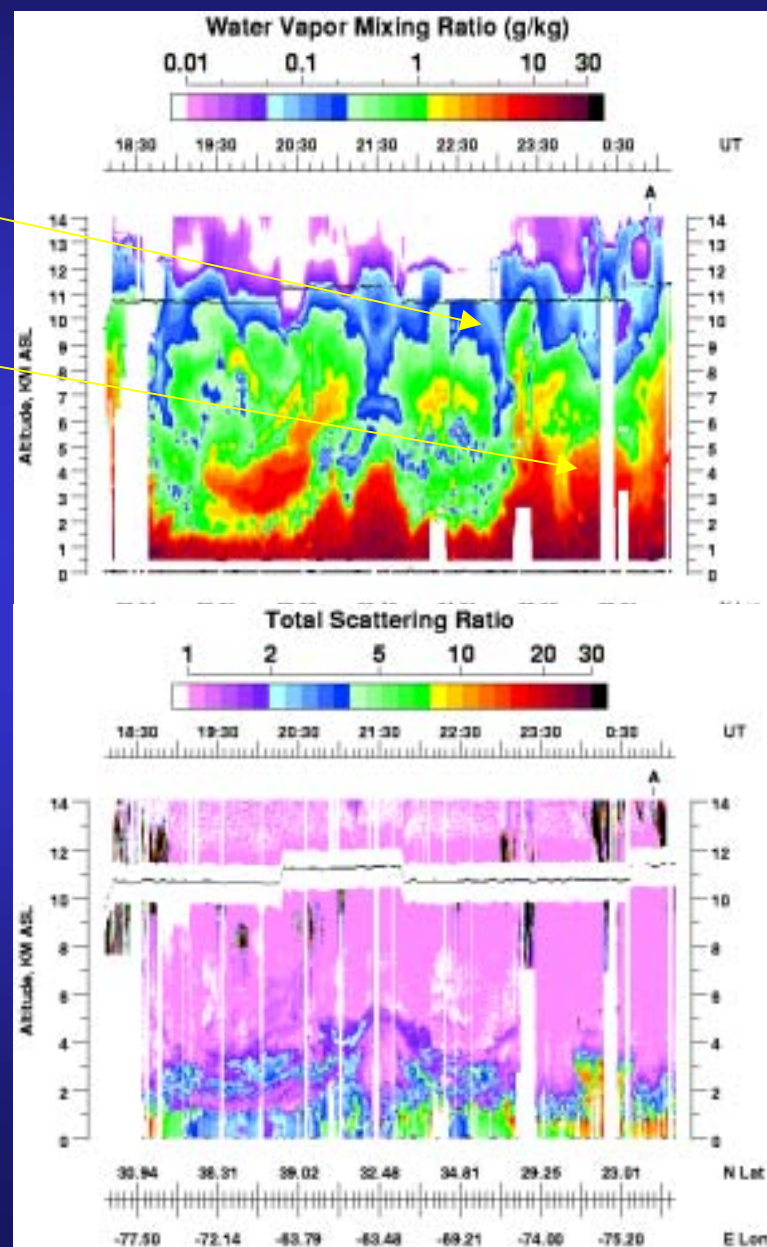
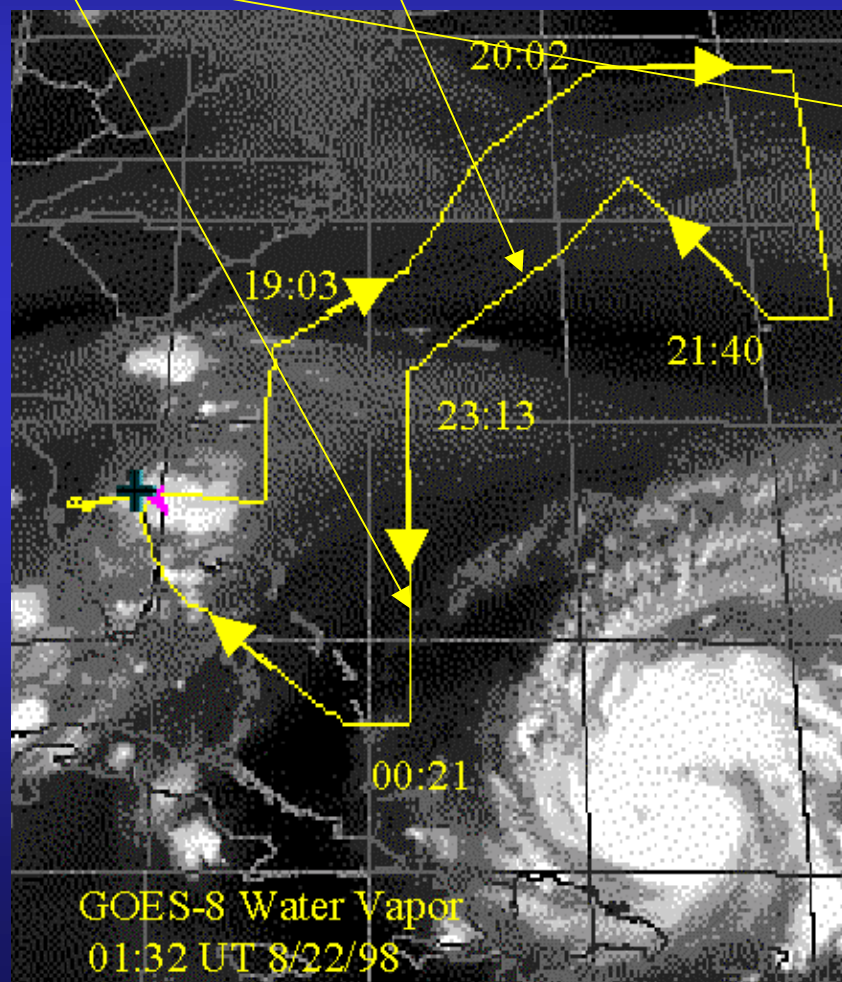
LASE Measurements during CAMEX-3

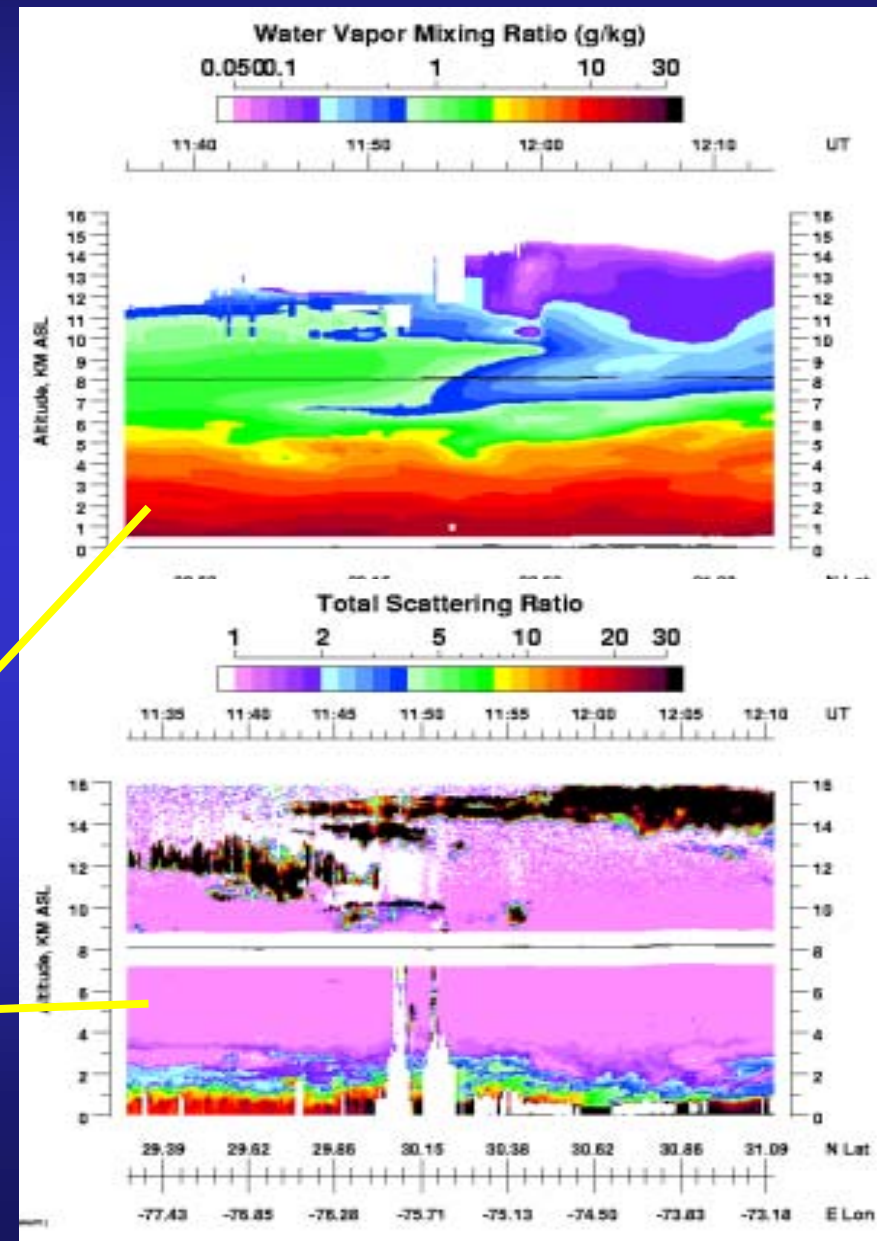
- Acquired data on 16 science flights
- Measurements in vicinity of 4 hurricanes (Bonnie, Danielle, Earl, Georges)

Date	Flight No.	Flight Duration	Hurricane	Objectives	Measurements
8/10	3	7:05		Transit	Instrument checkout
8/13	4	4:42		TEFLUN-B	Mostly cloudy -limited data
8/15	5	3:08		TEFLUN-B	Mostly cloudy -limited data
8/20	6	4:48		Convection off Florida	Mostly cloudy - limited data
8/21-22	7	8:43	TS Bonnie	Synoptic Flow ahead of TS	Extensive data in clear skies north and west of TS in pre-storm environment
8/23-24	8	6:39	Bonnie	Transit Survey and Eyewall	Data in clear skies during transit north of Bonnie - mostly cloudy and limited data in storm vicinity
8/24-25	9	7:48	Bonnie	Transit Survey and Eyewall	Limited data in cloudy areas within storm - limited data in pre-storm environment west of Bonnie
8/26	10	7:22	Bonnie	Inflow and Landfall	Data in clear sky inflow area south and southeast of storm-profile within eye
8/29-30	11	7:52	Danielle	Inflow and Vortex Motion	Extensive data in clear sky southeast inflow region - low level MACAWS coordination
8/30-31	12	7:47	Danielle	Inflow and Vortex Motion	Extensive data in inflow regions throughout southeast and southern inflow regions- low level MACAWS coordination
9/2	13	5:42	Earl	Rainbands	Mostly cloudy
9/5	14	4:47		TEFLUN-B	Mostly cloudy
9/13-14	15	6:08		Calibration / Validation	Extensive Andros Overflights in clear skies
9/14	16	4:23		TEFLUN-B	Mostly cloudy
9/15	17	5:01		TEFLUN-B	Mostly cloudy
9/21	19	4:42	Georges	Transit Survey and Eyewall	Data in clear regions northwest of storm during transits and southeast of storm
9/22-23	20	7:23	Georges	Synoptic Flow and Inflow	Data in clear sky region during transits north of storm and in inflow regions south of storm - low level MACAWS coordination

LASE CAMEX-3 Measurements: T.S. Bonnie Synoptic Flow

- Mid, upper troposphere drying far in advance of storm
- Increase in low level water vapor in storm vicinity

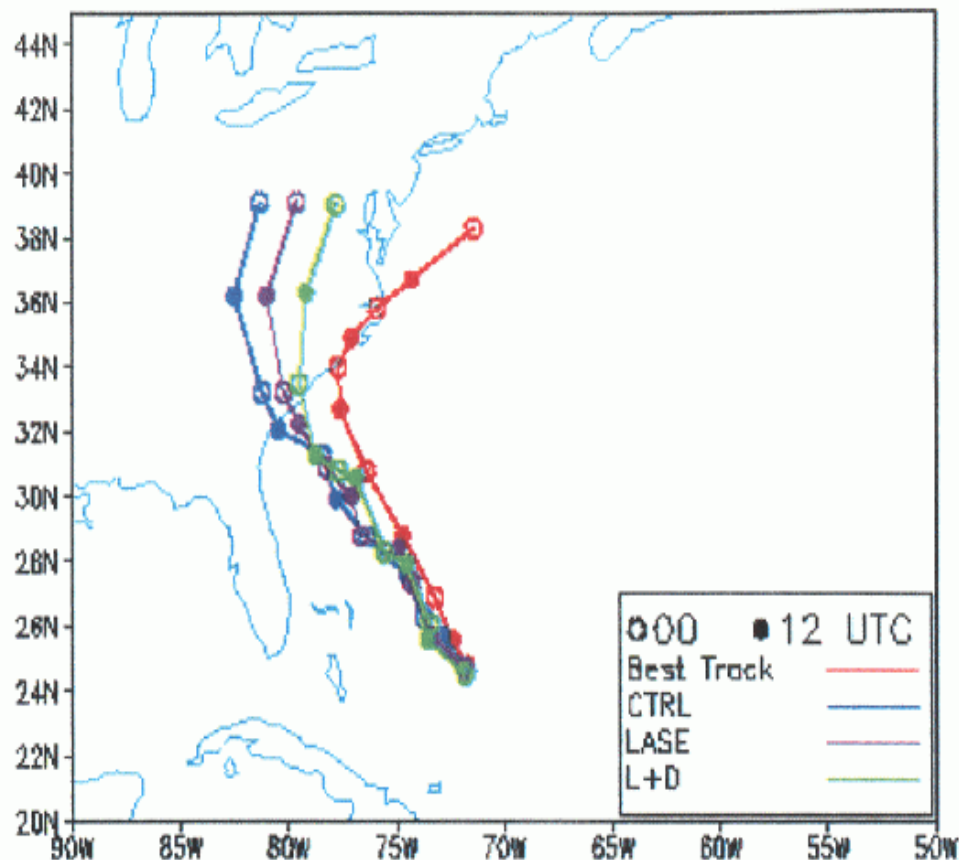




CAMEX-3 LASE Measurement Impact on Model Forecasts

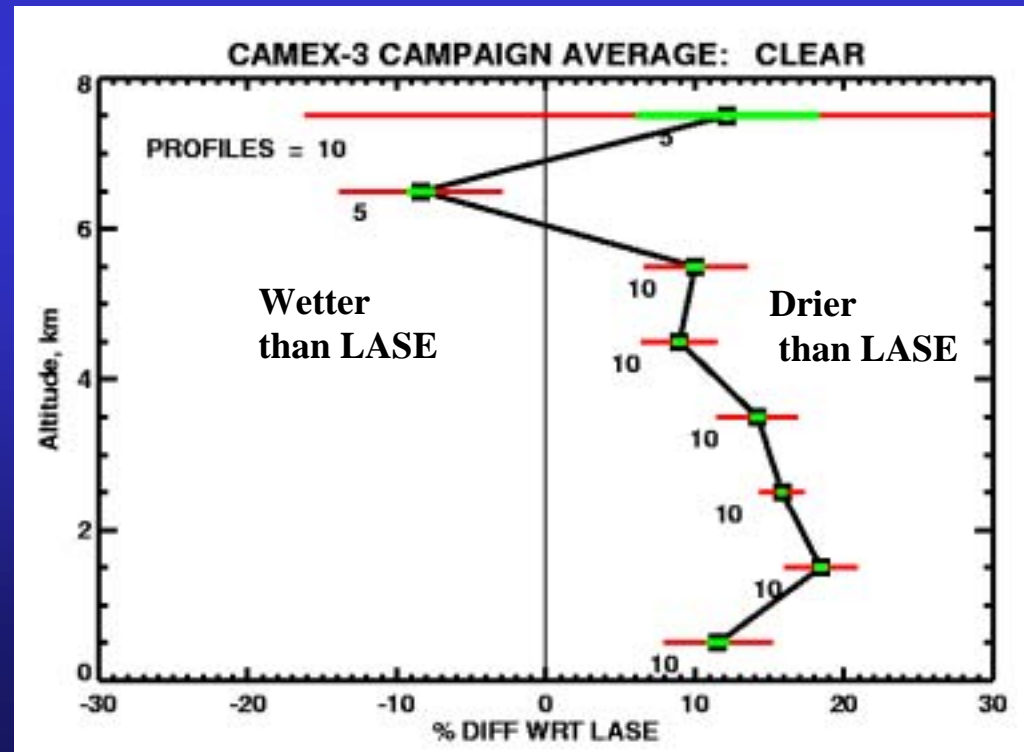
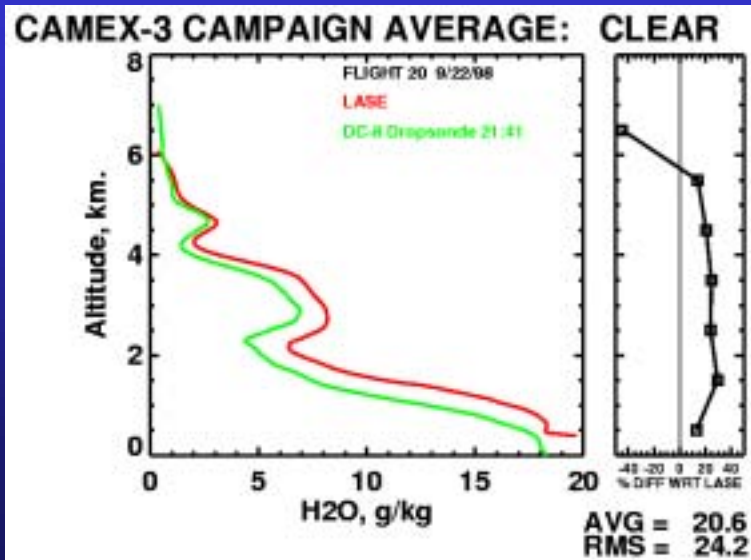
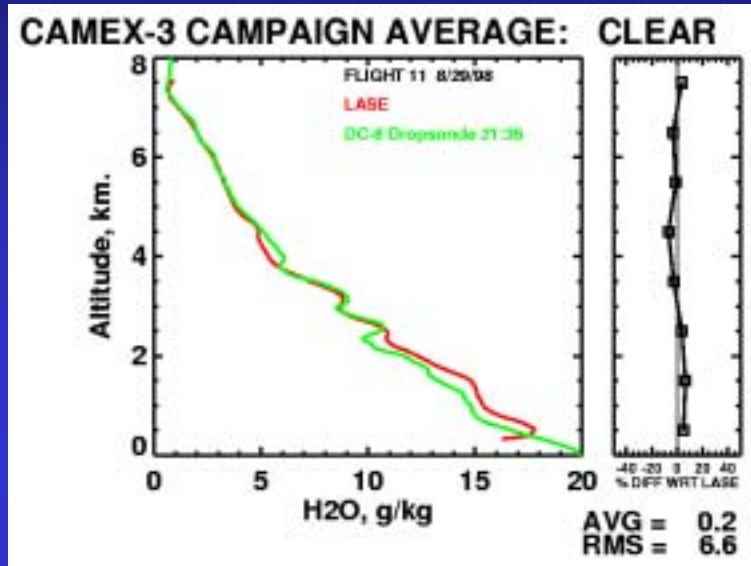
- Florida State Univ. Global Spectral Model Sensitivity tests
- LASE data provided improvement of 10-30% in the 48 to 72 hour forecasts of moisture
- Models using LASE water vapor data had smaller forecast track errors
- Models using LASE water vapor + dropsonde wind data had significantly smaller forecast track errors

(a) 120 Hour forecast track of Hurricane Bonnie
IC: 00 UTC 24 August 1998



LASE Assessment of CAMEX-3 DC-8 Dropsonde Water Vapor

- Periodic dropsonde dry bias
- 10 LASE/dropsonde comparisons
- Dropsonde ~15% drier on average
- Dropsonde dry bias may be due to outgassing of packaging material



LASE Measurements during CAMEX-4

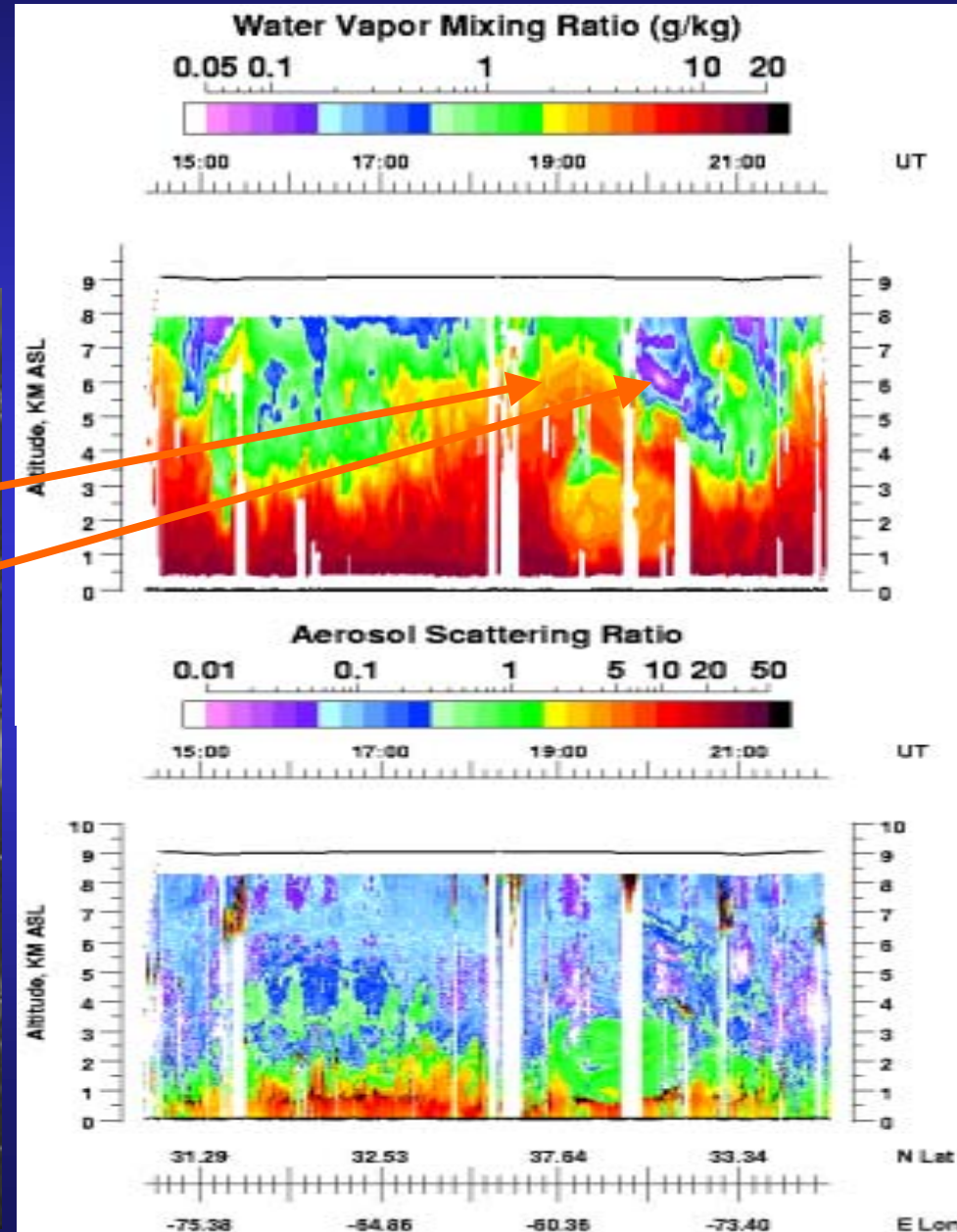
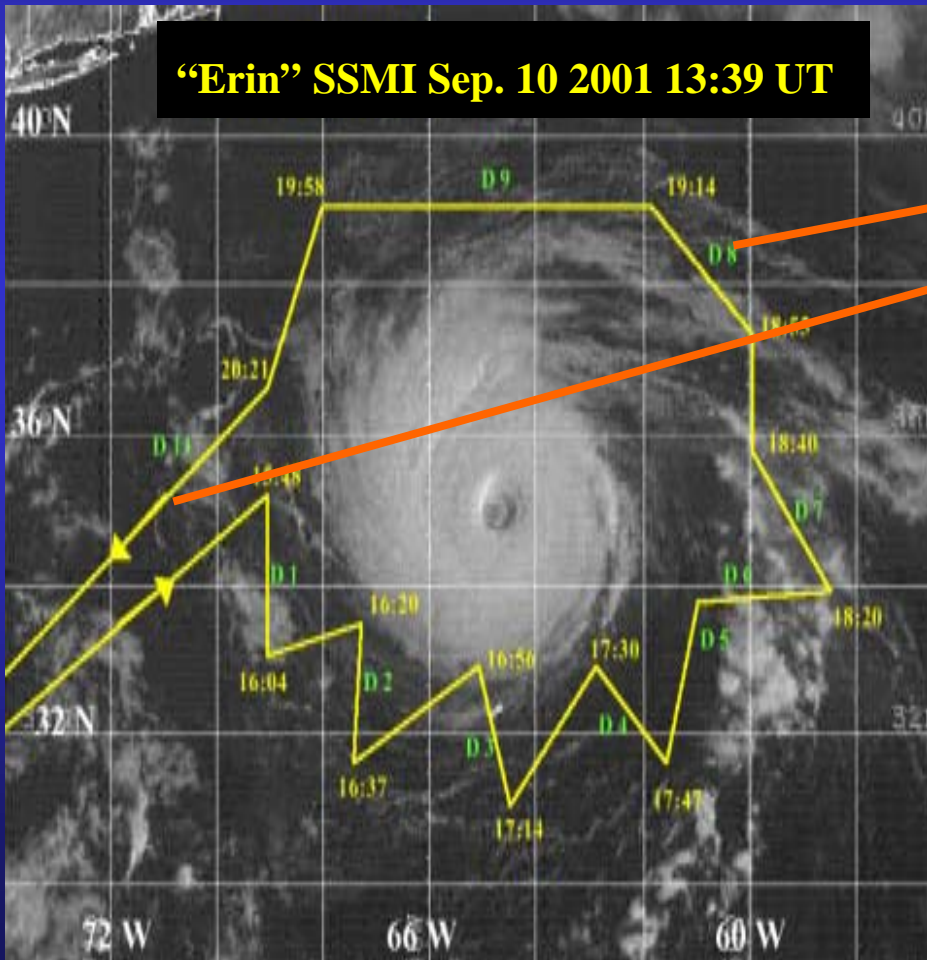
- Acquired data on 13 science flights
- Measurements in vicinity of 2 hurricanes (Erin, Humberto) and 2 tropical storms (Chantal, Gabrielle)

Date	Flight Number	Flight Duration (hours)	Objectives	Tropical Storm/Hurricane	LASE Measurements
8/15	5	4.8	Transit to JAX	N/A	Extensive data (4.0 hrs) (aerosol, wv, clouds distrib). Mostly clear sky across country.
8/18	6	3.5	Andros Island Calibration Flight	N/A	3.5 hours of LASE data. Excellent Atmospheric conditions with some cirrus.
8/20	7	7.5	Convection Emphasis with vertical structure, also rainband patterns flown	TS Chantel	+6.5 hrs of aerosol, Wv and cloud distro. Lots of clouds from approx 19:30 UT to end of mission.
8/25	8	2.0	Instrument test flight	N/A	+1.0 hrs of aerosol, wv, cloud distro. Fairly clear skys. Lots of aerosol fine structure.
9/03	9	5.0	KAMP #1 Convective structure of a precipitating system	N/A	+3.0 hrs of aerosols, wv, and cloud distro. Lots of structure, clouds, and cirrus above the DC-8.
9/06	10	1.0	Instrument Check/Convection	N/A	0.5 hrs of aerosols, wv, and cloud distro. Lots of clouds above and below DC-8 and other structure
9/07	11	5.0	KAMP #2, Convection in precipitating storm	N/A	+4.5 hrs of aerosols, wv, and cloud distro. Lots of clouds above and below DC-8
9/09	12	5.0	KAMP #3, Convection in precipitating storm.	N/A	+4.5 hrs of aerosols, wv, and cloud distro. Lots of clouds above and below DC-8.
9/10	13	8.0	Optimal data assimilation to collect comprehensive data on winds, temp, and moisture structure of the storm.	Hurricane ERIN	8.0 hrs of aerosols, wv, and cloud distro. Occasionally in and out of cirrus clouds. Excellent data set.
9/15	14	8.0	Optimal data assimilation and to map flow fields and thermodynamic fields in a rotated pattern.	TS GABRIELLE	+7.5 hrs of aerosols, wv, and cloud distro. In and out of cirrus above and below DC-8. Excellent data when not in the clouds.
9/19	15	5.0	KAMP #4, Sample a convective system to obtain radar and microphysics data	N/A	4.5 hrs of aerosols, wv, and cloud distro. In and out of cirrus above and below DC-8 throughout this flight. When not in clouds, has good data.
9/22	16	8.0	QPE mission and to map the conditions near a developing storm center, including flow fields and thermodynamics.	TS HUMBERTO	7.0 hrs of aerosols, wv, and cloud distro. In and out of cirrus above and below DC-8. Lots of excellent data and structure when not in clouds.
9/23	17	7.5	COVES #1, Convection, structure, and mapping of the inner storm	Hurricane HUMBERTO	6.0 hrs of aerosols, wv, and cloud distro. Excellent data when not in the storm. Lots of structure.
9/24	18	8.0	COVES #2, Convection, structure, and mapping of the storm	Hurricane HUMBERTO	7.0 hrs of aerosols, wv, and cloud distro. Excellent data when not in the storm. Lots of structure.

CAMEX-4 Hurricane Erin “Optimal Data Assimilation” Flight

- High water vapor northeast of storm
- Mid-upper level dry region associated with cold trough southwest of storm

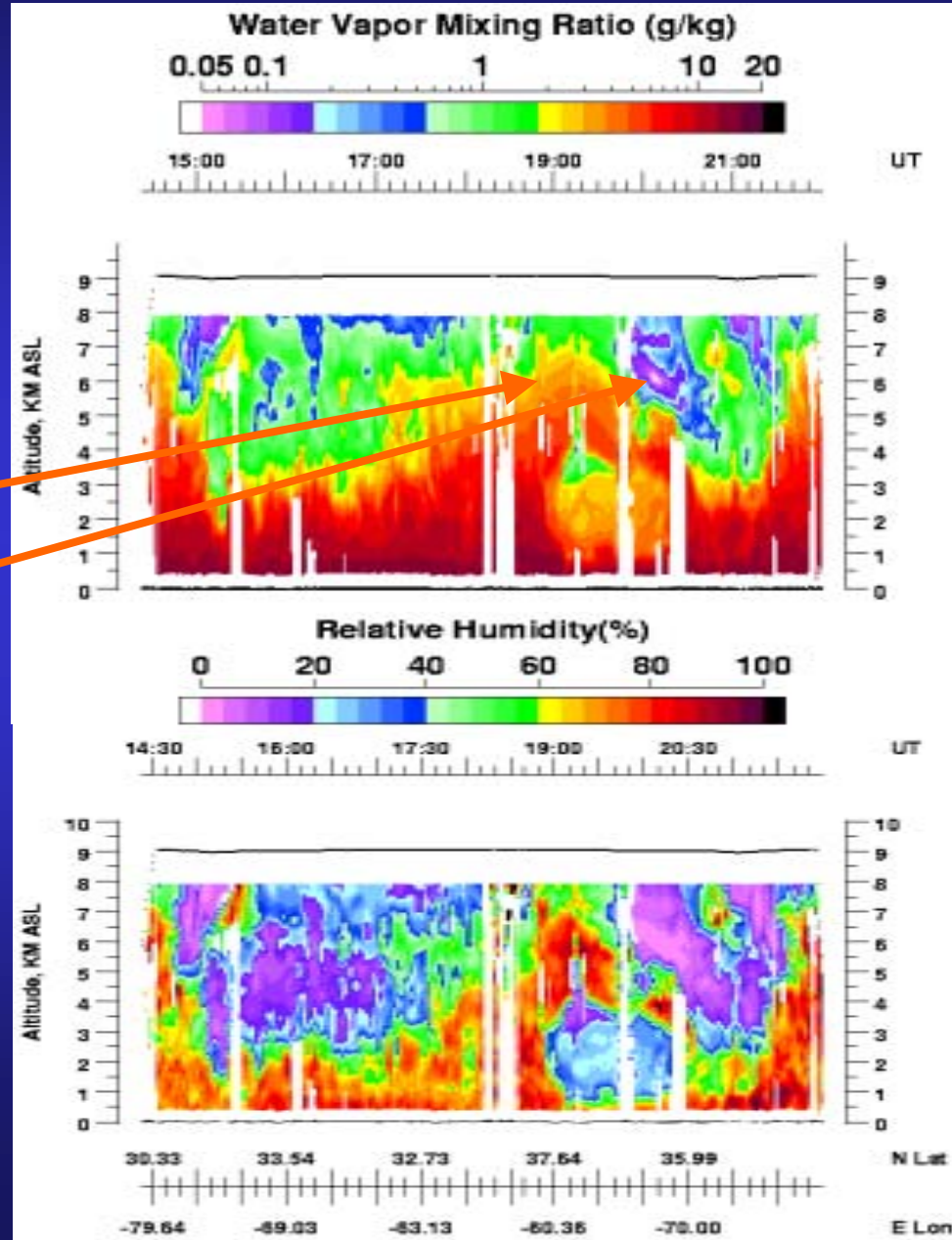
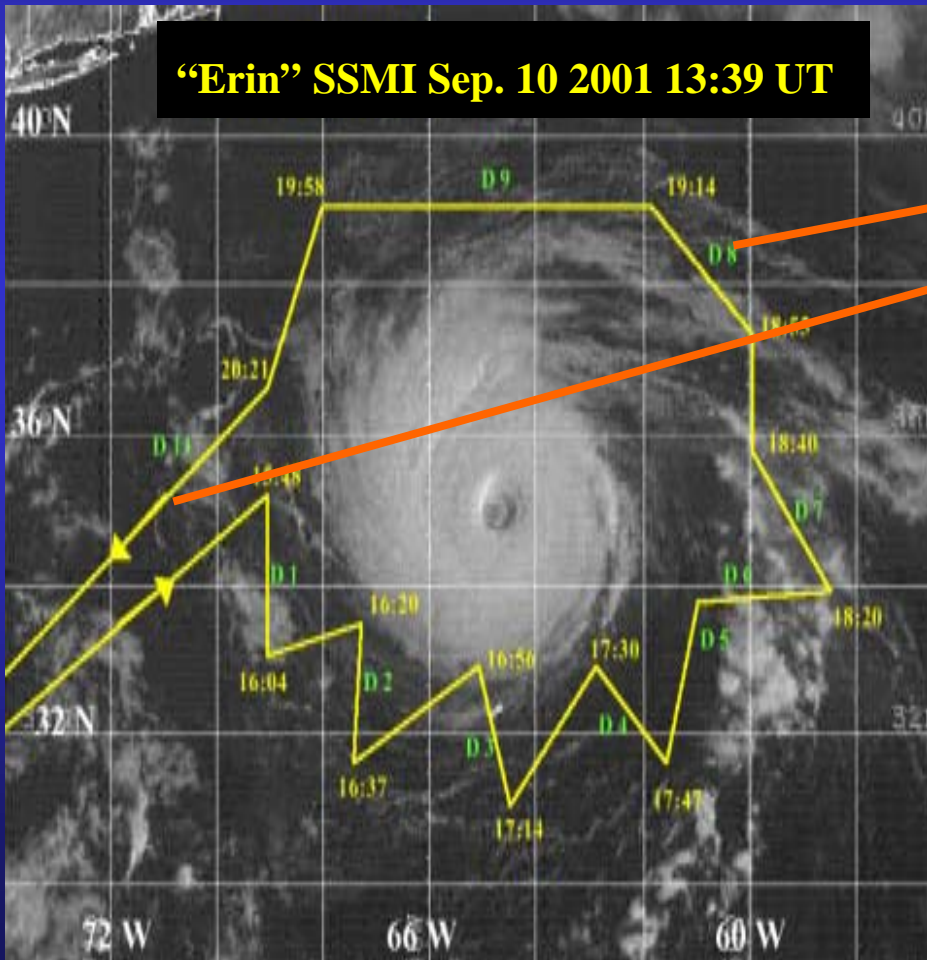
“Erin” SSMI Sep. 10 2001 13:39 UT



CAMEX-4 Hurricane Erin “Optimal Data Assimilation” Flight

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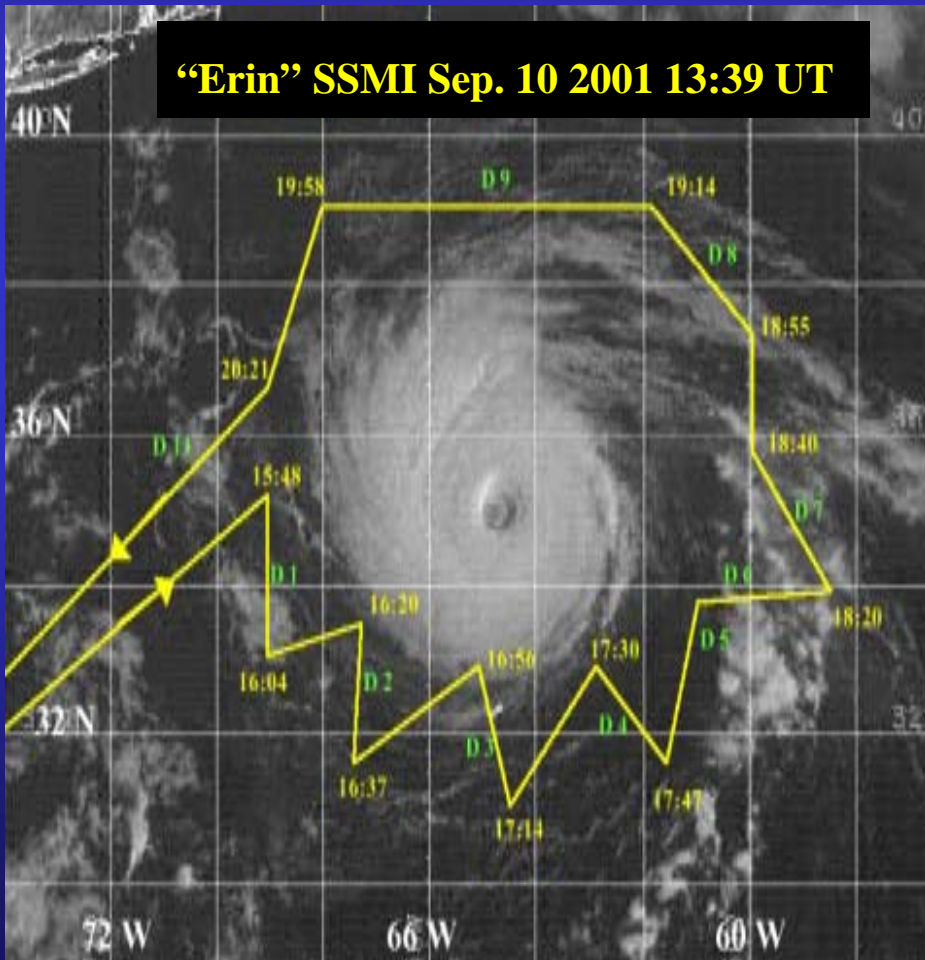
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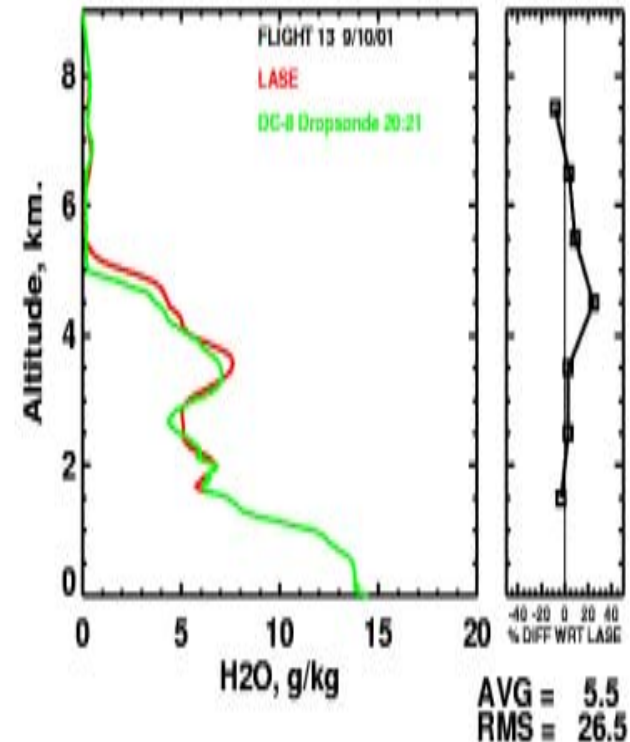
CAMEX-4 LASE/DC-8 Dropsonde Comparisons

- Initial comparisons from Flight 13
- Initial results show better agreement (within about 5-10%) between LASE and dropsonde water vapor profiles

“Erin” SSMI Sep. 10 2001 13:39 UT

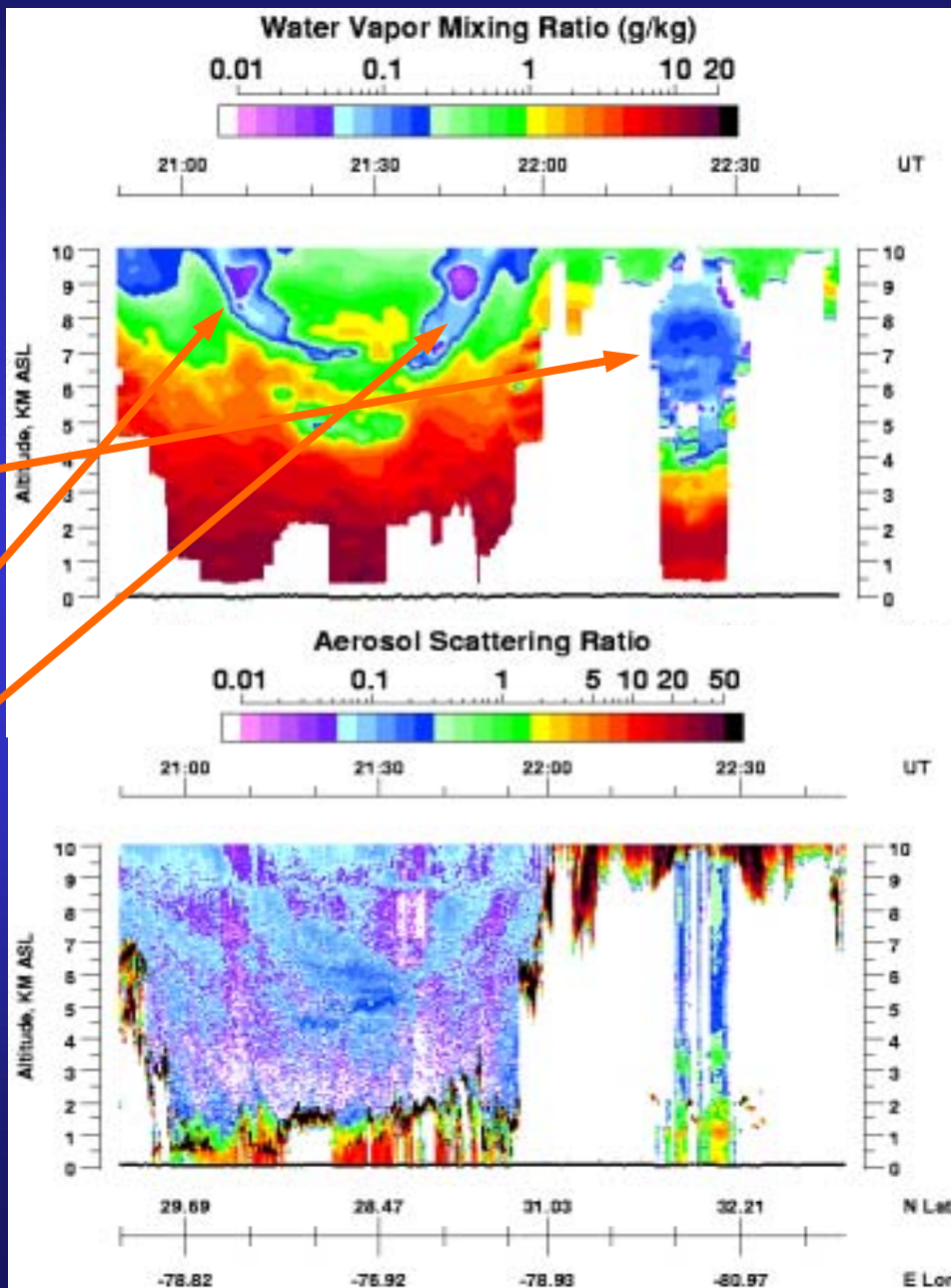
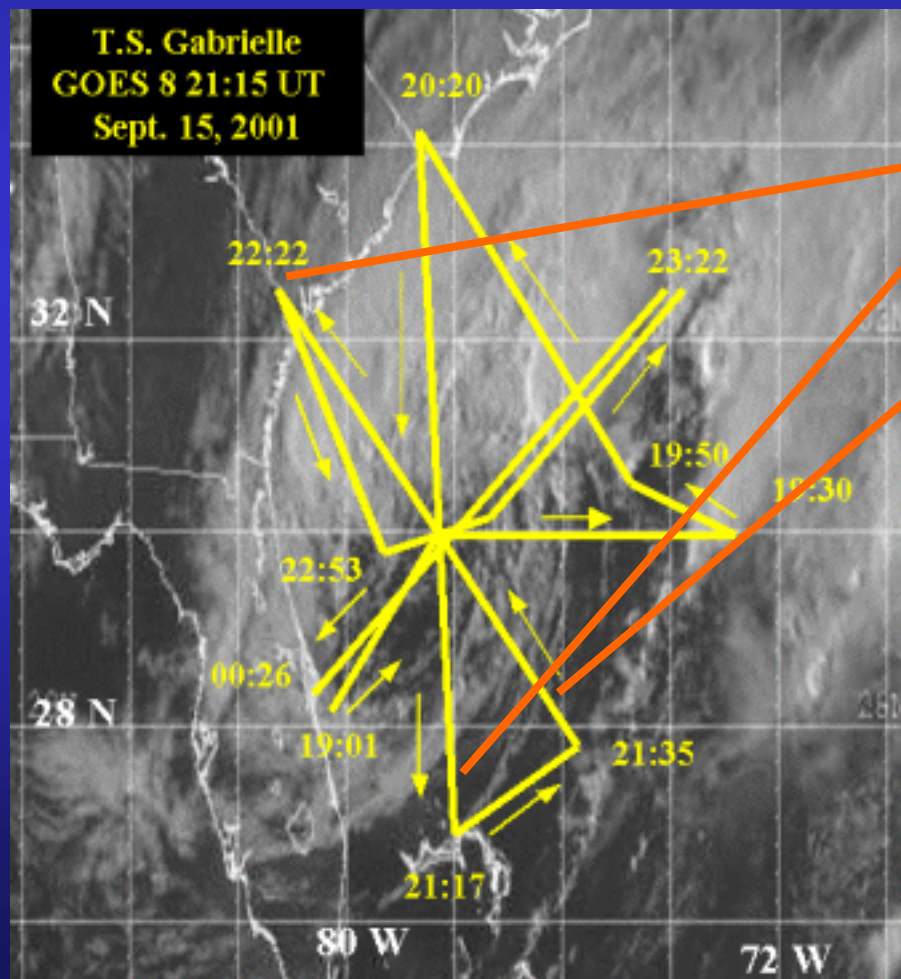


CAMEX-4 CAMPAIGN AVERAGE: CLEAR



CAMEX-4 Tropical Storm Gabrielle Flight

- Dry air between 7-11 km inhibited the rapid redevelopment of this tropical storm as it left the Florida coast



Future Work for LASE data acquired during CAMEX-4

Data Processing and Science analyses

- Preliminary LASE digital data and images are available from CAMEX-4 archive
- Complete final processing of LASE nadir and zenith data
 - anticipate completion (May 15)
 - archival (June 1)
 - contact us for possible prior availability
- Complete dropsonde (DC-8 and ER-2) water vapor comparisons
- Complete retrievals of RH profiles from LASE nadir and zenith water vapor and MTP/dropsonde temperature profiles
- Publications

Research Activities

- Characterize hurricane environment
 - Combine LASE nadir and zenith water vapor with DC-8 in situ (DLH)
 - Characterize upper troposphere RH and cirrus clouds
 - Retrieve cirrus cloud geometric and optical depth
 - Compute precipitable water vapor using LASE water vapor profiles
- Collaborate on assessing impact of LASE data on hurricane predictions
- Investigate stratosphere-troposphere exchange
- Others identified at this meeting?

Summary

CAMEX-3

- LASE made first DIAL measurements of water vapor, aerosol, and cloud distributions in hurricane environment (Bonnie, Danielle, Earl, Georges)
- LASE measurements showed
 - dry air subsiding ahead of hurricane
 - inflow of moist air in low levels
 - distribution of clouds, aerosol, and water vapor across rainbands
 - moisture structure across eye
 - periodic dry bias (~15%) of DC-8 dropsondes
- Model results
 - LASE moisture overall improvement of 10-30% in the 48 to 72 hour forecasts of moisture based on verification of the relative humidity variable (FSU)
 - LASE moisture profiles slightly (~100 km) reduce 3 day forecast track error of Hurricane Bonnie (FSU)

CAMEX-4

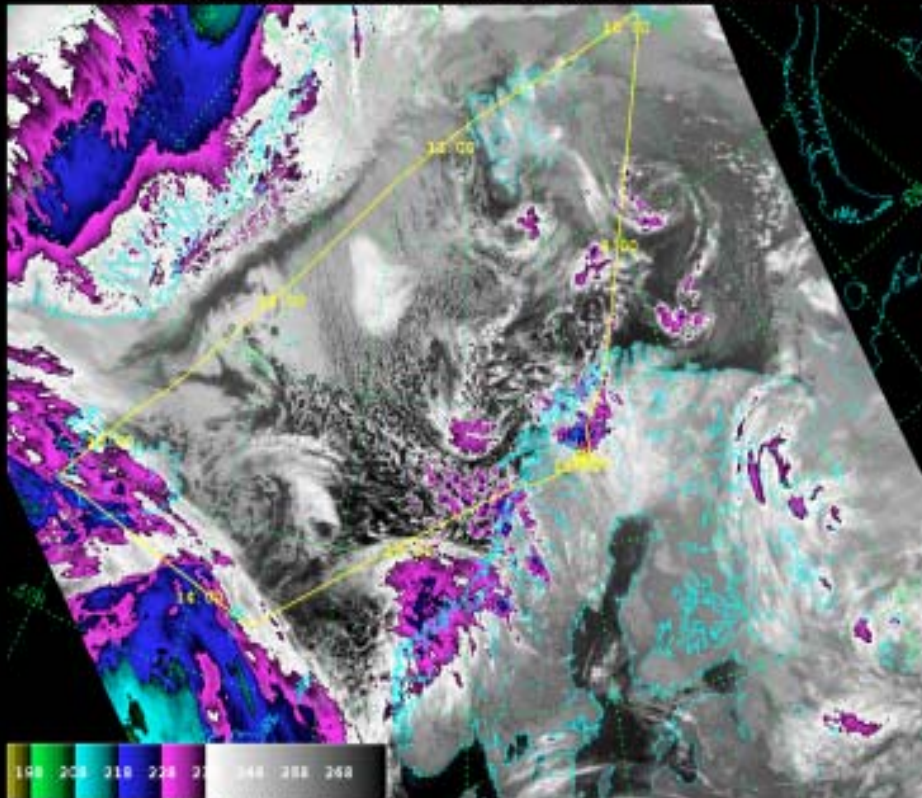
- LASE acquired data during all science flights and measured water vapor, aerosol, and cloud distributions in vicinity of 2 tropical storms (Chantal, Gabrielle) and 2 hurricanes (Erin, Humberto)
- Preliminary comparisons show better agreement between LASE and dropsonde water vapor profiles
- Final data archived ~ June 1
- Potential future science activities (collaborations welcome!) involving LASE measurements
 - upper troposphere relative humidity, stratosphere-troposphere exchange
 - assess impact of LASE measurements on model forecasts (FSU, others?)
 - cirrus cloud optical and geometrical thickness
 - precipitable water vapor

Research Activity - Upper Tropospheric Humidity Measurements

Upper Tropospheric Humidity (UTH)

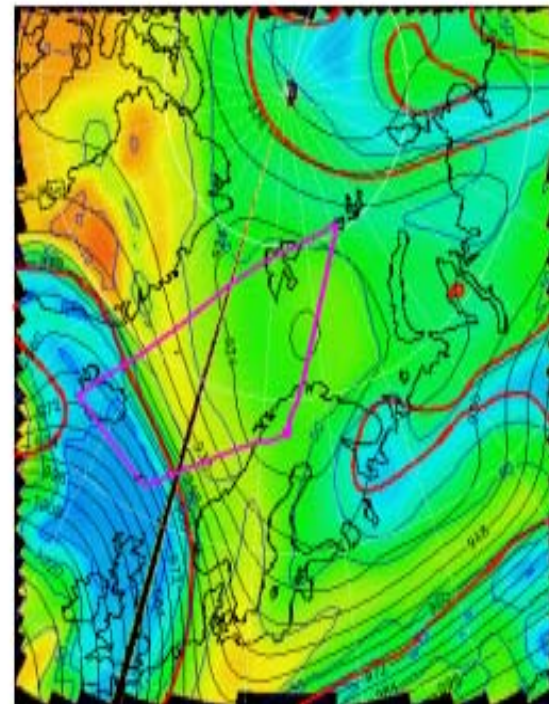
- Small changes in UTH have large impact on radiative transfer
- UTH impacts formation and persistence of cirrus clouds and contrails
- Use LASE water vapor (nadir and zenith) and MTP temperature to measure UTH (ice supersaturation) through large region in troposphere
- DC-8 Flight 8, December 5, 1999 (SOLVE)
- Jet stream north of Iceland with increase in RH and cirrus clouds south of jet

DC-8 19991205 NOAA-14 Ch5 1322 UT 05 Dec 1999



12 UTC on 5 December, 1999 at FL330 (262 mb)

ASM, Grid: 021H1
Seq: A-FLUX-01, Spec: -



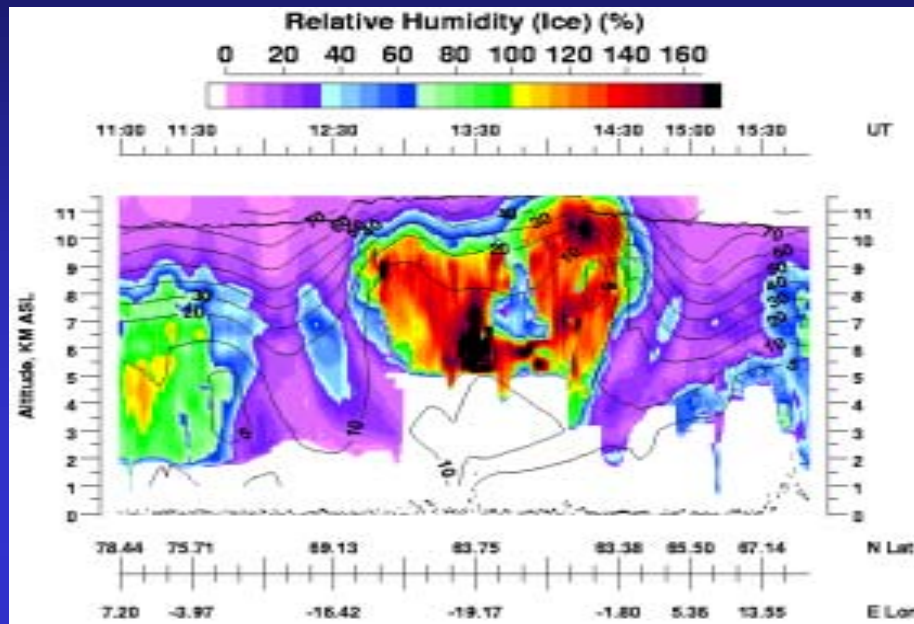
DC-8 19991205

NASA
ARC/GSFC

Trop (EPV=3.25e-6) Z (dam) RH (%)

(Plot courtesy of the NASA-Ames DC-8 meteorological support group and NASA -Goddard Code 916.)

Relative Humidity Measurements



- Decrease in water vapor associated with stratospheric air
- Higher water vapor and cirrus on southern side of jet stream
- LASE and DC-8 in situ instruments show presence of ice supersaturation

